As accepted by Journal of Applied Psychology

#922

Abstract

In diving, exposure to an air environment (79% nitrogen, 21% oxygen) at pressures in excess of 4-6 atmospheres absolute (ATA) produces subjective effects and performance changes commonly attributed to nitrogen narcosis. Two studies conducted in a hyperbaric chamber to test for adaptation to narcosis with repeated exposure to pressures of almost 7 ATA (185 feet sea water equivalent) are reported. In the first experiment, 10 participants made four dives at 3-day intervals to 188 fswg, and in the second experiment, eight men were exposed to 185 fswg on each of five successive days. Performances during the 45 minute exposures at maximum depth were compared with those obtained during decompression in the same dive at pressures comparable to 20 and 10 fswg. Both experiments produced the same results, performance was degraded at maximum depth relative to that at lesser depths, and performance improved at all depths with repeated exposures. These findings, and the absence of change in susceptibility to narcosis, are discussed with reference to adaptation.

PERFORMANCE EFFECTS WITH REPEATED EXPOSURE TO THE DIVING ENVIRONMENT

When air is used as the respiratory medium in underwater work, descent beyond 100 feet (fswg) will produce subjective and behavioral effects comparable to those produced by one or two cocktails. If the descent is continued to 300 fswg, where air supply pressure is 10 atmospheres absolute (ATA), the diver may become completely disoriented and disabled. These behavioral impairments were originally attributed to many variables including oxygen deficit, excess carbon dioxide and anxiety. It is now well established that the critical factors in production of these effects are the kind of inert gas present in the respiratory medium and the partial pressure of that gas (Bennett, 1975). For example, performance at pressures of 7-10 ATA (198-297 fswg) is impaired substantially relative to that at 1-2 ATA (0-33 fswg) when the respiratory medium is air which is 79% nitrogen (Bennett & Blenkarn, 1974), but performance is not impaired at the greater pressures relative to the lesser ones when the nitrogen is replaced by helium or hydrogen (Edel, 1974). Further, substitution of other gases such as argon (Fowler & Ackles, 1972) or nitrous oxide (Hamilton, 1973) for nitrogen produce even greater behavioral effects.

The name for the behavioral impairment, inert gas narcosis, is taken from the physical events which are known to precipitate it. Its dependence upon inert gas partial pressure makes it possible to study narcosis in the open ocean, wet hyperbaric chambers, or dry hyperbaric chambers. The two studies reported here were conducted in a dry hyperbaric chamber.

It has been suggested that emotional, motivational, and experiential factors may accentuate, or ameliorate, this intoxication of the deep but there is very little evidence regarding either type of interaction. The literature dealing with psychological factors accentuating narcosis consists of several attempts (Baddeley, deFigueredo, Curtis, & Williams, 1968; Davis, Osborne, Baddeley, & Graham, 1972; Osborne & Davis, 1976) to demonstrate that diving in open water generates anxiety which in turn potentiates narcosis. The literature regarding emotional, motivational, and experiential factors which may ameliorate narcosis is similarly deficient in convincing evidence for an effect of any of those factors on susceptibility to narcosis. Despite those deficiencies, the diving community seems to be convinced that frequent exposure to hyperbaric air reduces its narcotic effects. In the diving literature this purported amelioration is attributed to an otherwise undefined process, adaptation.

Aside from anecdotes, such as Zinkowski's report (1971) that divers felt less groggy after diving for several days than they did during the first day on a job at 200 fswg, there is surprisingly little evidence for diminution of narcosis ~~on~~ in man with repeated exposures. Adolfson and Muren (1965) mentioned in passing that narcosis diminished in successive hyperbaric chamber exposures to air at 13 ATA, and

Shilling and Willgrube (1937) reported that a sub-group of their subjects described as "acclimated" required less time to solve four arithmetic problems at all depths than did the larger subgroup of non-acclimated subjects. The only positive evidence of adaptation from an explicit attempt to evaluate the effects of successive exposures to air was reported by Moeller and Chattin (1975). They found that tracking performance of eight men at 7 ATA suffered less decrement on the second occasion than on the first. No such change was observed for two arithmetic tasks administered in the same experiment. A follow-up study with intervals of 3 and 28 days between exposures yielded no evidence of adaptation (Moeller, Chattin, Rogers, Laxar, & Ryack, Note 1). Whitaker & Findley (1977), working in the same laboratory, did not obtain evidence for adaptation in two exposures spaced one week apart. The studies to be reported here were conducted to determine whether or not the narcosis-induced performance decrement does diminish with larger numbers of successive relatively brief hyperbaric exposures.

Experiment 1

The first experiment conducted subsequent to Moeller and Chattin (1975) in the same laboratory compared change in narcosis decrement at 3 and 28 days following initial exposure (Note 1). From the negative outcome of that study and anecdotes attributed to working divers (Lanphier, 1964), it appeared that tests for adaptation should be based on a larger number of more closely spaced hyperbaric exposures. In this experiment, the cumulative effect on the narcosis decrement of four dives at successive three-day intervals was assessed. The three-day interval was selected as short enough to permit demonstration of any beneficial effects of the repeated hyperbaric exposure and long enough to minimize the risk of decompression sickness consequent to retention of inert gas over repeated dives.

Method

Subjects. Twelve qualified men, ages 21-48, volunteered to participate in this experiment. One man suffered an ear squeeze at the beginning of his second exposure, but completed the remaining dives. Personal business prevented another, who had completed training, from participating in the hyperbaric tests. This report is based on the data from the ten men who completed the experiment. Each of those ten men had been exposed at least four times previous to this experiment to pressures of 4 ATA or more, and six had 10 or more such experiences.

Apparatus. Training and tests were conducted in the Naval Submarine Medical Research Laboratory hyperbaric chamber which has been certified by the Naval Facilities Engineering Command for operation at pressures up to 156 psi (350 fswg equivalent). This chamber is 9 feet (2.74 m) in diameter and is divided into a 13 foot (3.96 m) inner lock and an 8 foot (2.44 m) outer lock. A test station was sited at each of the three chamber ports so that three subjects could participate in the experiment simultaneously. Tracking (TRK) and one kind of manual dexterity (NSBS) task were administered at one station; short-term memory (STM) and signal detection (SD) tasks were presented at another, and addition (ADD), response orientation (RT), and a second manual dexterity (MINN) task were used at another. The subjects, seated in student type desk-chairs, viewed stimuli for most tasks through a 13 inch (33 cm) internal diameter port. The tracking task hardware has been described previously (Moeller & Chattin, 1975). The commercially available Bennett Hand Tool Test (NSBS) was administered at the TRK station. The stimuli for the STM and SD tasks were presented by a Kodak Model 850H, 300W projector on a Polacoat Model LS-40 rear projection screen located outside the viewing port. Timing of stimulus projection and inter-stimulus interval, when required, was controlled by Scientific Prototype 1000 series programming modules. The subject wrote his responses on a form appropriate to each of those tasks. ADD and RT were computer-controlled (NOVA 1220) tasks. Responses were obtained via a calculator-type keyboard located inside the chamber while the stimuli were presented via closed circuit TV located outside the chamber. The second manual dexterity task was the two-handed turning subtest of the Minnesota Rate of Manipulation Test.

Tasks. Four of the seven tasks used to assess performance were adaptive: pursuit tracking (TRK); addition-subtraction (ADD); short-term memory (STM); and response orientation (RT). In the tracking task, amplitude of the target's path varied directly with level of performance. When a subject tracked well, score increased linearly; otherwise, score increased following a sawtooth pattern. For ADD, STM, and RT, discrete response tasks, time allowed for response was adjusted from session to session during training to force each person to continue to work near the limit of his ability as skill improved. Time limits were fixed for each subject during the experiment proper at the value he achieved on completion of training. This adaptive technique was used to counter a common problem in study of environmental stressors, the subject whose performances under control and experimental conditions do not differ because he did not exert maximum effort until the stressor was imposed.

The tracking and arithmetic tasks were used in the Moeller and Chattin study (1975). Adaptive tracking was implemented as in the earlier study. ADD (Adams, 1958) was automated in this experiment to permit adjustment of stimulus presentation time to match each subject's capabilities. A correct answer in training reduced the time allowed for solution by 100 msec, and an incorrect answer increased it by 100 msec. For sets of 30 ADD problems, time allowed for solution during the narcosis tests was 5 sec to 10 sec per problem. Mean accuracy at the conclusion of training was 67%.

The short-term memory and signal detection tasks were implemented as in previous studies (Edel, 1974). The Paced Sequential Memory Task (Lloyd, Reid, & Feallock, 1960) provided a link to the literature on memory. At the conclusion of training the mean accuracy of recall for 40 STM items was 80% for projection rates of 17-24 slides per minute. In the signal detection task (SD) a target appeared as a high density column in a "noisy" 48 x 60 dot matrix. At the conclusion of training, the average (mean) subject identified 72.4% of a set of 63 targets.

The response orientation task (RT) is an adaptive form of the Continuous Reaction Time task (Poulton, 1970). The subject entered the five odd integers on the keyboard as each appeared on the TV monitor. Subjects were instructed to use a touch system with "5" as the home key. At each test depth two sets of 30 RT problems were presented with a 30 second rest interposed. Maximum permitted RT varied across subjects from 600 msec to 700 msec. Mean accuracy at the conclusion of training was 74%.

The Bennett Hand Tool Test (NSBS) has been used in several variations (Baddeley, et al, 1968; Hamilton, 1973).in many studies of diver performance. In addition to its widespread use in personnel selection, MINN has been identified as a "factorially-pure" measure of arm-and-hand dexterity (Rim, 1962). Experimenters outside the chamber timed performance of both tasks. At the conclusion of training, mean time per trial was 247 seconds for NSBS and 40 seconds for MINN.

A simple narcosis questionnaire was administered to each subject immediately after he had completed the last dive in the series of four. He was asked to rank the four exposures in terms of experienced narcosis, and then to assign a value to each on a scale in which "1" meant stone cold sober and "5" meant intoxicated as could be and still move.

Design and Procedure. In each of the four dives conducted at three day intervals, the test exposure was 188 fswg for 45 minutes or less. Control data were obtained from tests administered at 20 and 10 fswg during decompression from the test exposure. The experimental design called for four replications of three men each. As a result of the subject attrition subsequent to training noted earlier, two men were tested during the second exposure in the third replication and only two participated in the tests of the fourth replication.

Training was conducted in the hyperbaric facility at 1 ATA in one hour daily sessions during the week preceding the first hyperbaric exposure. Beginning with the fourth session, the subjects in a replication trained as a group following the task rotation procedure to be used at maximum depth in the hyperbaric tests. Prior to the hyperbaric exposures per se each subject "warmed-up" by performing the tasks assigned to his starting position. Approximately 12 minutes were required to complete all tasks at each station. Subjects moved from station to station beginning the cycle at each depth at the station last occupied.

Control measures were taken during the pauses at 20 and 10 fswg required by the decompression schedule rather than at sea level prior to compression. Bennett concluded on review of the diving literature that, "These results indicate an increasing decrement in performance with increasing air pressure which is first apparent at 4 ATA (100 ft.)" (1975, p 208). That conclusion, the report by Fenz and Epstein (1967) that anticipating stress may be more traumatic than experiencing it, and constraints on time available for each day's exposure prompted that choice of control measure. Further, exposing divers to air at 185 fswg for 45 minutes, as in this study, Whitaker and Findley (1977) confirmed that the narcosis-induced performance decrement is independent of order of experimental and control conditions as administered in this experiment. Performances measured prior to compression (1 ATA), during a pause at 10 fswg in compression to 185 fswg, during the 10 fswg decompression stop, and at the end of decompression (1 ATA) were substantially the same, and reliably superior to that at 185 fswg. Other studies in the same laboratory have confirmed directly that performance at 1 ATA prior to compression, and at 20 and 10 fswg during decompression are equivalent (Moeller & Rogers, Note 2).

The procedures prescribed by the U.S. Navy Diving Manual for compression to depth and for decompression from an air dive to 190 fswg for 50 minutes were followed.

Results

Analyses described below were based on the following: mean within-trial change in the adaptive tracking factor, ΔC; arcsine transformation of signal detection percentage; mean number of correct responses for STM and ADD per depth; number of correct responses for RT per 30 trial block; total time to complete the Hand Tool Dexterity Test (NSBS) and mean time to complete the Minnesota Rate of Manipulation Turning (MINN) subtest over four trials. Unless otherwise indicated, all significance levels refer to a within-subjects ANOVA, with depth and dive as the independent variables, based on the 10 men who completed all phases of the experiment.[2] Appropriate adjustments in statistical analyses were made for the MINN, SD, and NSBS since they were administered at only 188 fswg and 10 fswg.

Figures 1 and 2 show the subject's performance during the last day of practice (*) and during each of the four hyperbaric exposures for each of the seven measures. Performance within each exposure is shown for the tests at maximum depth (B) and at the 20 and 10 fswg decompression stops.

Insert Figures 1 and 2 about here

Depth exerted a significant effect on all the task measures shown in Figures 1 and 2 except SD. Failure of the tracking apparatus in the third dive of one replication made it necessary to omit data from Figure 1 and the analyses. Newman-Keuls tests showed that in all relevant cases performance at maximum depth (B) was reliably inferior to that at the decompression stops. Performances at the 20 and 10 fswg stops did not differ reliably from each other in any of those cases.

Mean level of performance varied significantly over the four dives (three for TRK) for all measures shown in Figures 1 and 2 except STM and SD. The Newman-Keuls tests showed that the significant dive effect for the tracking task derived from the inferior performance on Day 0 relative to that on Days 3 and 9. The uniform spacing of the dives over time in this experiment made it possible to apply tests for trends, instead of the Newman-Keuls test, to data from all tasks except TRK. There were reliable linear trends for the ADD, RT, MINN, and NSBS tasks over days. Apparently the general level of performance increased consistently from dive to dive for all of those tasks.

There was no evidence of a change in magnitude of decrement from dive to dive. None of the depth x dive interactions were statistically significant.

All but one subject assigned the first dive to either the first or second rank with respect to subjective narcosis. That subject rated all four dives as "3" in degree of narcosis. The median rated degree of narcosis for all dives was 3, "a mild glow."

Experiment 2

Anecdotal evidence from working dives (Lanphier, 1964) implies that adaptation to nitrogen narcosis may occur only when the interval between successive dives does not exceed one day. However, use of such intervals increases the risks of decompression sickness (bends). All theories of decompression sickness imply that other causal factors are synergistic with interval between hyperbaric exposures once the latter falls below threshold. The previous experiment tested for adaptation to narcosis with interdive intervals well above the presumed threshold. Rigorous test of the working divers' assumption now required a closer approach to the threshold for induction of decompression sickness.

Method

Subjects. Twelve qualified men, ages 23-29, volunteered to participate in this experiment. Of the eight participants who completed all five dives in the series, four had fewer than 10 previous exposures to pressures of 4 ATA or more, and four had more than 20 previous exposures.[3]

Apparatus. Training and tests were conducted with the facilities used in Experiment 1 changed as described below. There were four test stations through which the three subjects rotated to perform tests at a given depth. At the test station added for this experiment, standing steadiness was assessed using a Kristal Model 9261A stabilimeter system.

Tasks. Four of the seven tasks used in Experiment 1, tracking (TRK), addition (ADD), response orientation (RT), and the turning subtest of the Minnesota Rate of Manipulation Test (MINN), were presented in Experiment 2. At the conclusion of training, the time allowances and mean accuracies were: 5.5 to 9.5 seconds and 56.7% for ADD; and 500 to 600 msec and 60.0% for RT. Mean time to complete MINN was 40.1 seconds. The short-term memory, signal detection and Bennett Hand Tool tasks were replaced by the measure of standing steadiness (STB).

STB was administered following the procedure described by Adolfson, Goldberg, and Berghage (1972). Standing at relaxed attention with feet together (Romberg position), the subject completed a 30-second calibration trial and four 70-second trials at each test depth in the sequence, eyes open-closed-open-closed. Inter-trial rest interval was 30 seconds. The stabilimeter scores were obtained by analog integration of signals generated by sway in the lateral and sagittal planes. It was assumed that this measure would be less subject to influence by motivational and learning factors, particularly the latter, than are most performance measures.

The narcosis questionnaire was again administered immediately on completion of decompression from the last of the five hyperbaric exposures.

Design and Procedure. With the exceptions described previously, the design and procedures of this experiment, including controls, were identical to those of its predecessor. Test exposures were conducted at 185 fswg on five consecutive days instead of 188 fswg on four occasions separated by three day intervals.

Results

Within subjects designs were used for all ANOVAs. Dive (5) and depth (3) were the independent variables for ADD, TRK, and RT. Analysis of the MINN data again differed in restriction of test administration to two depths, maximum and 10 fswg. The effects of stabilimeter plane (2) and eye state (2) were evaluated along with those for dive (5) and depth (3) for STB. Figure 3 shows the performances of the eight men who completed all phases of the experiment for the four tasks administered and scored as in the previous experiment. The decompression schedule required termination of testing at maximum depth before MINN could be administered to all subjects during the first dive in three replications. For that reason, MINN data for only the last four dives are shown in Figure 3 and treated in the ANOVAs to be discussed below. The lower panel of Figure 4 shows the effects of depth and dive on the stabilimeter scores for the eight men, and the upper panel shows the effect of depth, eye state and direction of body sway. In both figures, the vertical axes have been oriented so that adequacy of performance is shown by distance above the baseline.

Insert Figures 3 and 4 about here

Analyses of variance confirmed that performances varied with depth for all five measures taken in this experiment. Newman-Keuls tests showed that performances at maximum depth (B) were reliably inferior to those at either the 20 or 10 fswg decompression stops, and that performances at the latter depths did not differ reliably from each other. Depth also accentuated the effects of both eye state (open or closed) and the axis of measurement (lateral or sagittal) on STB performance, i.e. two- and three-way interactions were statistically reliable. Eye state alone also affected STB performance, but there was no over-all difference in amount of sway in the two axes. Pressurization (depth) and closing the eyes had roughly equivalent effects on postural stability as measured.

Analyses of variance confirmed that scores varied over dives for the four performance measures. Tests for trends confirmed statistically that mean level of performance increased linearly over the five dives. There was no evidence in the STB data of any change in standing steadiness with successive exposure at any depth. Once more, there was no evidence of a change in the depth-induced performance decrement from dive to dive. None of the depth x dive interactions were statistically significant.

Seven of the eight divers who completed the experiment assigned the first dive to either the first or second rank with respect to subjective narcosis. The remaining subject rated degree of narcosis in the first dive slightly below that for the second and third dives. Median rating of narcosis over trials was 3, "a mild glow."

General Discussion

The diving literature (e.g., Bennett, 1975) implies that induction of narcosis is essential to development of adaptation and that extent of adaptation is an inverse function of length of interval between exposures.

The procedures employed have induced narcosis and the range of intervals suggested by the literature (e.g., Bulenkov, Maurer, Samoilouv, Tuiren & Visniakov, 1968; Lanphier, 1964) has been sampled without producing adaptation. Other studies in progress in our laboratory will show whether or not continuous exposure to hyperbaric air does produce adaptation. That possibility has not heretofore been considered explicitly in the literature.

In the context of the diving literature (Bennett, 1975), the statistically reliable decrements in performance at maximum depth relative to that at 20 and 10 fswg mean that the subjects suffered nitrogen narcosis in every test exposure of both experiments. In Experiment 1, SD proved to be insensitive to changes in air pressure. In Experiment 2, the increase in body sway produced by closing the eyes was expected as were the synergistic relations of eye state, axis of motion and depth (Adolfson, et al, 1972). For all the tasks subject to practice effects, the significant dive effects and the results of the trend tests, including the Newman-Keuls test for the TRK task in Experiment 1, provide unequivocal evidence that level of performance at maximum and control depths improved from dive to dive. In contrast, the differences for all those tasks between performance levels at maximum and control depths remain constant over exposures, i.e. there is no evidence of adaptation to narcosis in the figures or in the depth x dive interactions. The constancy of the STB scores, which were assumed not to be subject to practice effects, at both test and control depths reinforces the argument that adaptation to narcosis does not occur in the kinds of hyperbaric air exposures described here.

The reliable change in performance at both maximum and control depths with repeated exposure is the key to resolution of the discrepancy between the positive reports of others (Adolfson & Muren, 1965; Shilling & Willgrube, 1937) and the failure to find adaptation in the experiments reported here. Apparently, the earlier reports were based solely on general observations of behavior at depth at the beginning of the diving project and subsequently (Adolfson, Note 3), or on comparisons of measures taken on a single occasion at each of several depths (Shilling & Willgrube, 1937). The studies reported here were the first concerned with adaptation to narcosis in which measures were taken at test and control depths in each of several successive dives. The data for performances at maximum pressure in Figures 1-3 exhibit the kind of trend described in the positive reports regarding adaptation. Performance at maximum pressure (B) during the first dive is poorer than it had been during practice, then it improves over dives until performance at 188 fswg in the last dive approaches, or exceeds, that at 1 ATA at the end of practice.[4]

If control measures were not available for each exposure, one could argue that adaptation occurred in the two experiments reported here. However, as noted previously, when control performance is considered, there is no evidence for adaptation.

If one demands that control performance be "at asymptote," that conclusion might be questioned because in these experiments control performance improves over exposures. There are at least three reasons for rejecting any argument for use of asymptotic level of performance as a control for environmental, or stressor effects. First, as Bryan and Harter showed long ago (1899), and everyone's personal experience demonstrates, performance of any moderately complex tasks can improve substantially with intensive, properly guided and well-motivated practice. Attainment of a fixed level in many laboratory tasks reflects insensitivity of the task, inadequate training procedures, or poor motivation. Second, some subjects discriminate sharply between "just practice" and the real thing improving remarkably when the experiment proper begins, and most persons probably respond in a similar, but much less marked fashion. Third, Eich (1980) among others has discussed these context effects in learning and recall. Those findings imply that any change in context of test administration, as from practice to decompression control, should produce a decrement in performance which would disappear with practice in the new context.

Reports that severity of experienced narcosis decreases from dive to dive (Lanphier, 1964) have been offered as another kind of evidence for adaptation to narcosis. The same kind of data was obtained from the questionnaires administered in these experiments. Discrepancies between behavioral, or other objective, data and self-report measures of an individual's response to an event are common in the stress literature (Johnson, 1970). In the diving context, it's important practically, as well as theoretically, to recognize that behavioral and experiential aspects of narcosis are not highly correlated. The appropriate conclusion is that [behavioral] adaptation to hyperbaric air does not occur, but that subjective adaptation does, and that for safety's sake the objective effects rather than the subjective ones must guide conduct of diving operations.

Four different kinds of events observed in hyperbaric environments have been treated in the literature as relevant to adaptation to narcosis. The situation of other species exposed for the first time to an hyperbaric environment (Walsh & Bachrach, 1974) must be similar to that of a human thrust without warning into a totally novel, life-threatening one. Although it is important to understand the psychology of this kind of stress, the critical variables must be different from those operative in the context of repeated dives by a human formally trained in the physics and physiology of diving and qualified by experience and demonstration of physical suitability as a Navy diver or hyperbaric chamber technician. A second kind of event, disruption of partially-learned performance by emotional arousal is well-known in the stress literature (Poulton, 1970; Wilkinson, 1969). Weltman and Egstrom (1966) have shown that exposure to non-narcotic, but potentially dangerous, hyperbaric environments can produce this kind of performance disruption. The very poor TRK performance on first exposure at 7 ATA in the Moeller and Chattin experiment (1975) may reflect this kind of decrement. The apparently stable narcosis-induced decrement obtained in the experiments reported here is the third kind of event relevant to adaptation. Assuming that performance, as measured in these experiments, must eventually reach an asymptotic level, the question remains whether the decrement would decrease. If it did, then a search for the mechanisms of that change would be in order, and, when found, the mechanisms might properly be labelled adaptation. If the decrement persisted, it would imply that the negative finding of these studies apply over all time intervals. Finally, repeated exposure to depth for brief intervals does reduce the subjective magnitude of narcosis. However, discussion of this change in the diving literature implies much more, that the impairment of ability to perform is alleviated concomitantly. Application of the concept adaptation in this context not only confounds phenomena and mechanisms, it invites the unwary to ignore potentially life-threatening incapacity.

Reference Notes

1. Moeller, G., Chattin, C., Rogers, W., Laxar, K., & Ryack, B. L. Resistance to narcosis at interdive intervals of 3 and 28 days. Unpublished manuscript, Naval Submarine Medical Research Laboratory, Groton, CT.
2. Moeller, G., & Rogers, W. H. State dependent learning in a hyperbaric environment. Paper presented at the 20th annual meeting of the Psychonomic Society, Phoenix, AZ, November 1979.
3. Adolfson, J. Personal communication, July 17, 1974.

References

Adams, O. S. Aircrew fatigue problems during extended endurance flight, Phase I: Planning. WADC 57-510, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio, 1958.

Adolfson, J., & Muren, A. Air breathing at 13 atmospheres. Psychological and physiological observations. Försvarsmedicin, 1965, 1, 31-37.

Adolfson, J. A., Goldberg, L., & Berghage, T. Effects of increased ambient air pressures on standing steadiness in man. Aerospace Medicine, 1972, 43, 520-524.

Baddeley, A. D., deFigueredo, J. W., Curtis, J. W. H., & Williams, A. N. Nitrogen narcosis and performance under water. Ergonomics, 1968, 11, 157-164.

Bennett, P. B. Inert gas narcosis. In P. B. Bennett & D. H. Elliott (Eds.) The physiology and medicine of diving and compressed air work. (2nd ed.) Baltimore, MD: Williams & Wilkins, 1975.

Bennett, P. B., & Blenkarn, G. D. Arterial blood gases in man during inert gas narcosis. Journal of Applied Physiology, 1974, 36, 45-48.

Bryan, W. L., & Harter, N. Studies on the telegraphic language. The acquisition of a hierarchy of habits. Psychological Review, 1899, 6, 345-375.

Bulenkov, S. Y., Maurer, A. F., Samoilouv, B. P., Tuiren, V. I., & Visniakov, V. A. Illnesses peculiar to underwater swimming and adverse effects due to them. 9. Nitrogen narcosis. Manual of SCUBA diving, "Spravochnik Ploutsa-Podvodnika"; Publishing House of the Ministry of Defense, 1968. Translation JPRS:47,828 by U.S. Dept. of Commerce, 1969.

Davis, F. M., Osborne, J. P., Baddeley, A. D., & Graham, I. M. P. Diver performance: Nitrogen narcosis and anxiety. Aerospace Medicine, 1972, 43, 1079-1082.

Edel, P. O. Report on Project Hydrox II. Michel Lecler Inc., Harvey, LA, 1974.

Eich, J. E. The cue-dependent nature of state-dependent retrieval. Memory & Cognition, 1980, 8, 157-173.

Fenz, W. D., & Epstein, S. Gradients of physiological arousal in parachutists as a function of an approaching jump. Psychosomatic Medicine, 1967, 29, 33-51.

Fowler, B., & Ackles, K. N. Narcotic effects in man of breating 80-20 argon-oxygen and air under hyperbaric conditions. Aerospace Medicine, 1972, 43, 1219-1224.

Hamilton, R. W., Jr. Comparative narcotic effects in performance tests of nitrous oxide and hyperbaric nitrogen. Federation Proceedings, 1973, 32, 682.

Johnson, L. A psychophysiology for all states. Psychophysiology, 1970, 6, 501-516.

Lanphier, E. H. Man in high pressures. In Handbook of Physiology, Sect. 4, Adaptation to the Environment. Washington, DC: American Physiological Society, 1964.

Lloyd, K. E., Reid, L. S., & Feallock, J. B. Short-term retention as a function of the average number of items presented. Journal of Experimental Psychology, 1960, 60, 201-207.

Moeller, G., & Chattin, C. P. Situation-specific experience and nitrogen narcosis in the diving environment. Journal of Applied Psychology, 1975, 60, 154-158.

Osborne, J. P., & Davis, F. M. Diver performance -- Nitrogen narcosis and anxiety. In Drew, E. A., Lythgoe, J. N., & Woods, J. D. (Eds.), Underwater research. New York: Academic Press, 1976.

Poulton, E. C. Environment and human efficiency. Springfield, Illinois: Thomas, 1970.

Rim, Y. The predictive validity of seven manual dexterity tests. Psychologia, 1962, 5, 52-55.

Shilling, C. W., & Willgrube, W. W. Quantitative study of mental and neuromuscular reactions as influenced by increased air pressure. U.S. Naval Medical Bulletin, 1937, 35, 373-380.

Walsh, J. M., & Bachrach, A. J. Adaptation to nitrogen narcosis manifested by timing behavior in the rat. Journal of Comparative and Physiological Psychology, 1974, 86, 883-889.

Weltman, G., & Egstrom, G. H. Perceptual narrowing in novice divers. Human Factors, 1966, 8, 499-506.

Whitaker, L. A., & Findley, M. S. Nitrogen narcosis measured by dual-task performance. Journal of Applied Psychology, 1977, 62, 735-746.

Wilkinson, R. Some factors influencing the effect of environmental stressors upon performance. Psychological Bulletin, 1969, 72, 260-272.

Zinkowski, N. B. Commercial oilfield diving. Cambridge, MD: Cornell Maritime Press, 1971.

Footnotes

The interpretations and opinions contained in this article are those of the authors only and do not necessarily represent the view of the U.S. Navy. Portions of this paper were presented at the 1977 convention of the American Psychological Association.

Requests for reprints should be sent to George Moeller, Naval Submarine Medical Research Laboratory, Box 900, Naval Submarine Base New London, Groton, Connecticut 06349.

[2]Throughout this paper reference to significant or reliable effects means *p* less than or equal to .05.

[3]Participation of the remaining four men ended when they reported joint pain during, or subsequent to, decompression. In all cases symptoms were relieved by standard treatment. Since two of the four men reported joint pain after only one exposure, the increased incidence of bends relative to that in the previous experiments cannot be explained solely in terms of the shorter interval between exposures.

[4]A final change in task parameters for eight subjects probably accounts for the relatively poor performance in the last RT training session for Experiment 1.

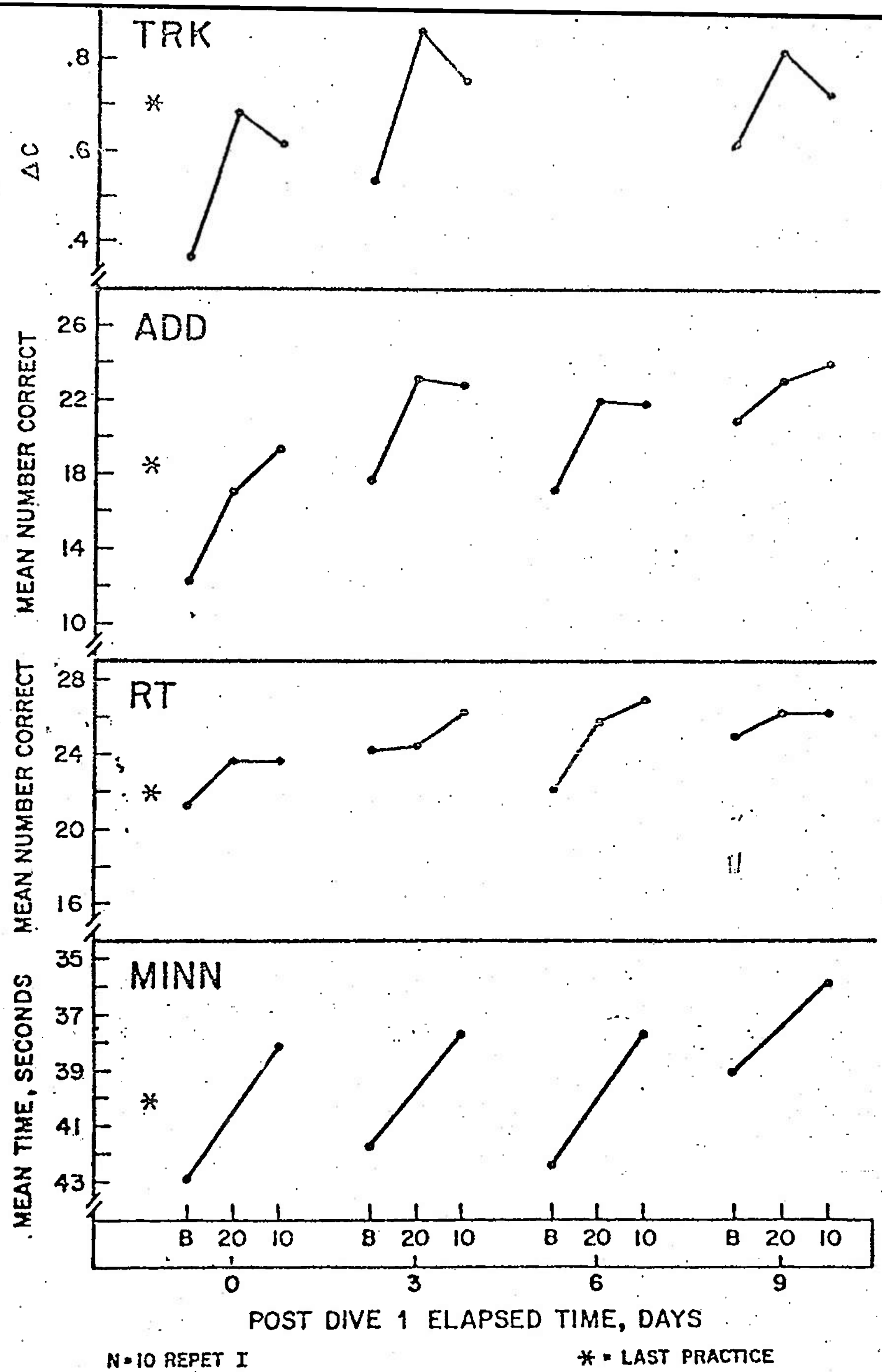
FIGURE CAPTIONS

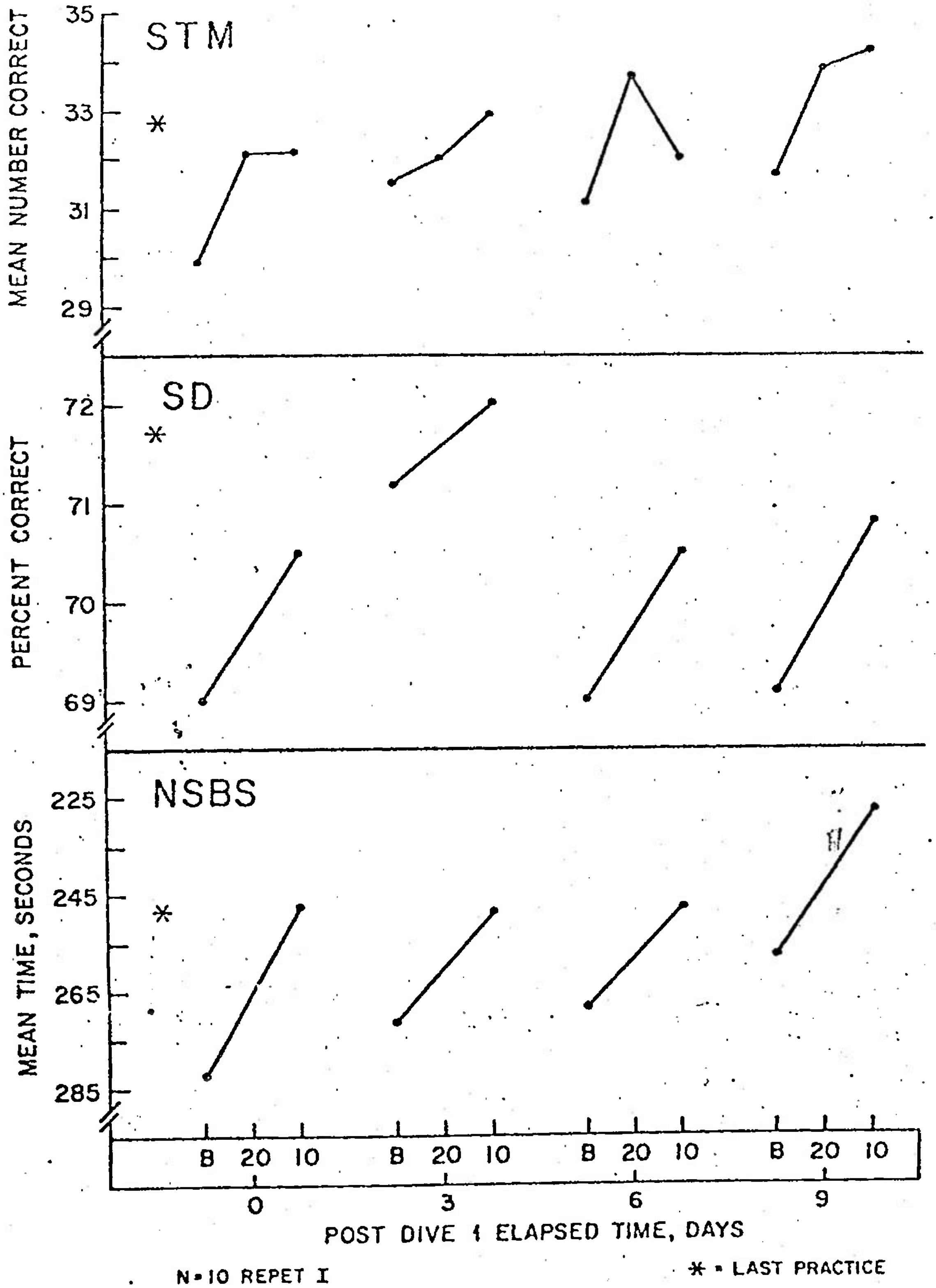
Figure 1. TRK, ADD, RT and MINN performances at maximum depth (B) and during decompression stops (20, 10) in hyperbaric air exposures at 3-day intervals. MINN was not administered at the 20 fswg stop.

Figure 2. STM, SD, and NSBS performances at maximum depth (B) and the 10 fswg decompression stop in hyperbaric air exposure at 3-day intervals. STM was also administered at the 20 fswg decompression stop.

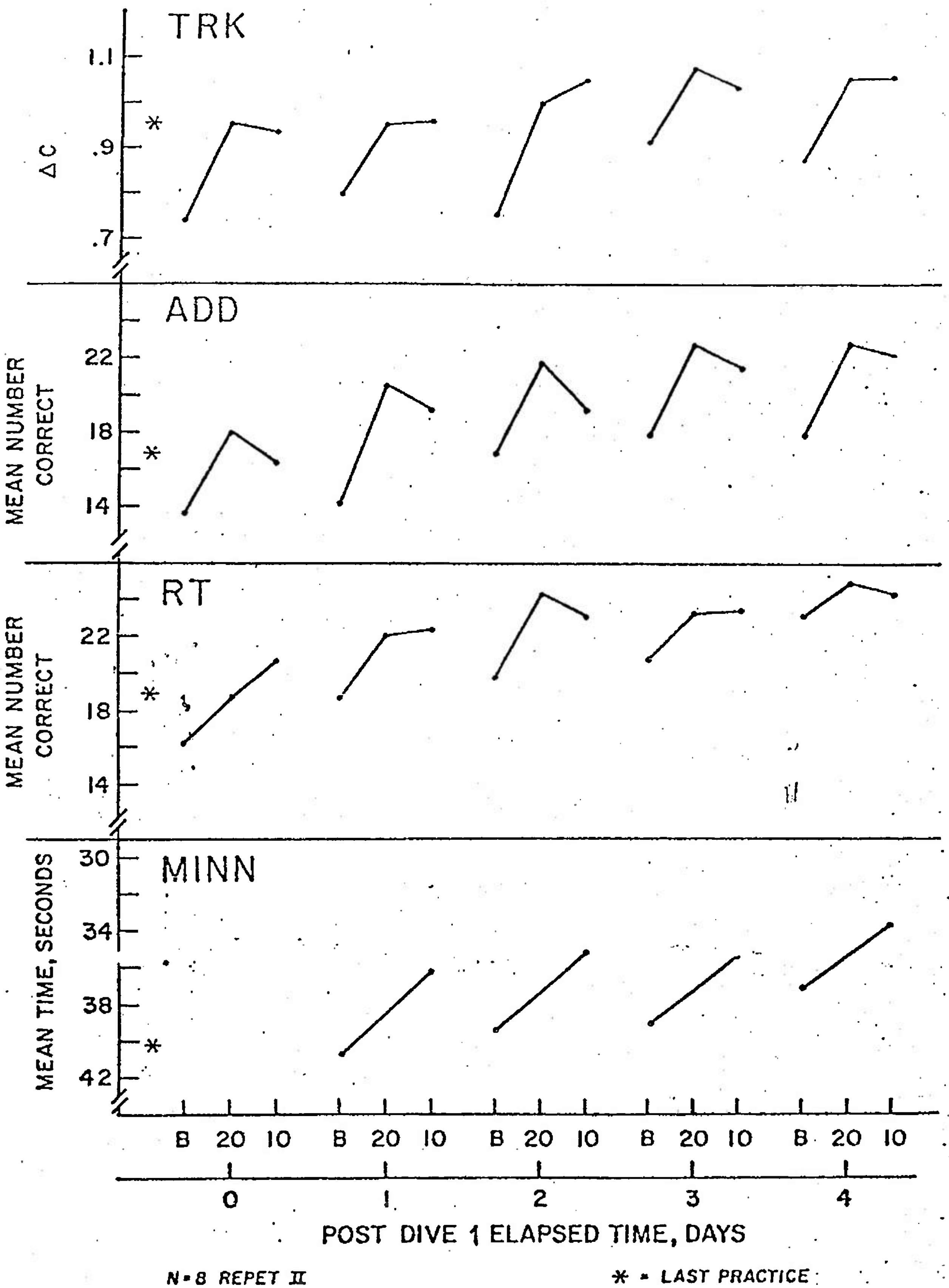
Figure 3. TRK, ADD, RT and MINN performances at maximum depth (B) and during decompression stops (20, 10) in hyperbaric air exposures at 1-day intervals. MINN was not administered at the 20 fswg stop.

Figure 4. (UPPER) Postural stability as a function of: hyperbaric pressure, eye state, and axis of measurement.
(LOWER) Stability at maximum depth (B) and during decompression stops (20, 10) in hyperbaric air exposures at 1-day intervals.

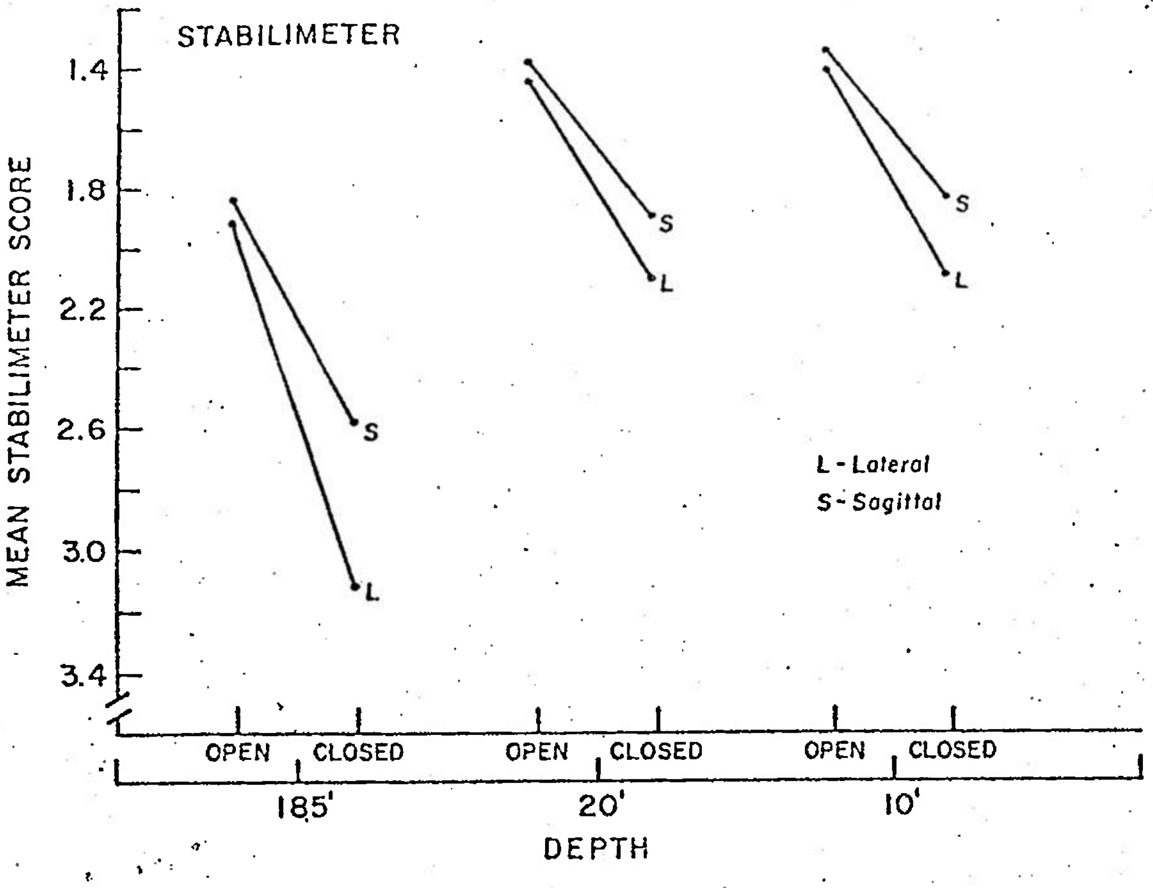

TRK
ΔC
.8
.6
.4
ADD
MEAN NUMBER CORRECT
26
22
18
14
10
RT
MEAN NUMBER CORRECT
28
24
20
16
MINN
MEAN TIME, SECONDS
35
37
39
41
43
B 20 10 B 20 10 B 20 10 B 20 10
0 3 6 9
POST DIVE 1 ELAPSED TIME, DAYS
N=10 REPET I
* = LAST PRACTICE



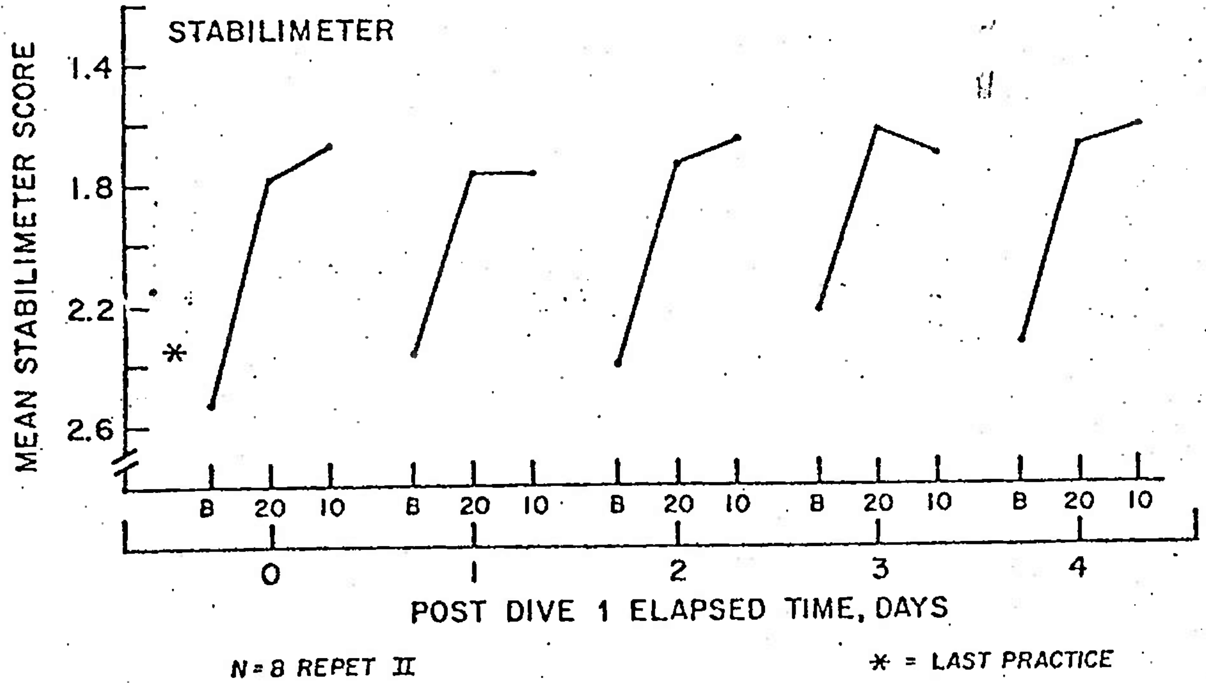
STM
MEAN NUMBER CORRECT
35
33
31
29
SD
PERCENT CORRECT
72
71
70
69
NSBS
MEAN TIME, SECONDS
225
245
265
285
B 20 10 B 20 10 B 20 10 B 20 10
0 3 6 9
POST DIVE 1 ELAPSED TIME, DAYS
N=10 REPET I
* = LAST PRACTICE



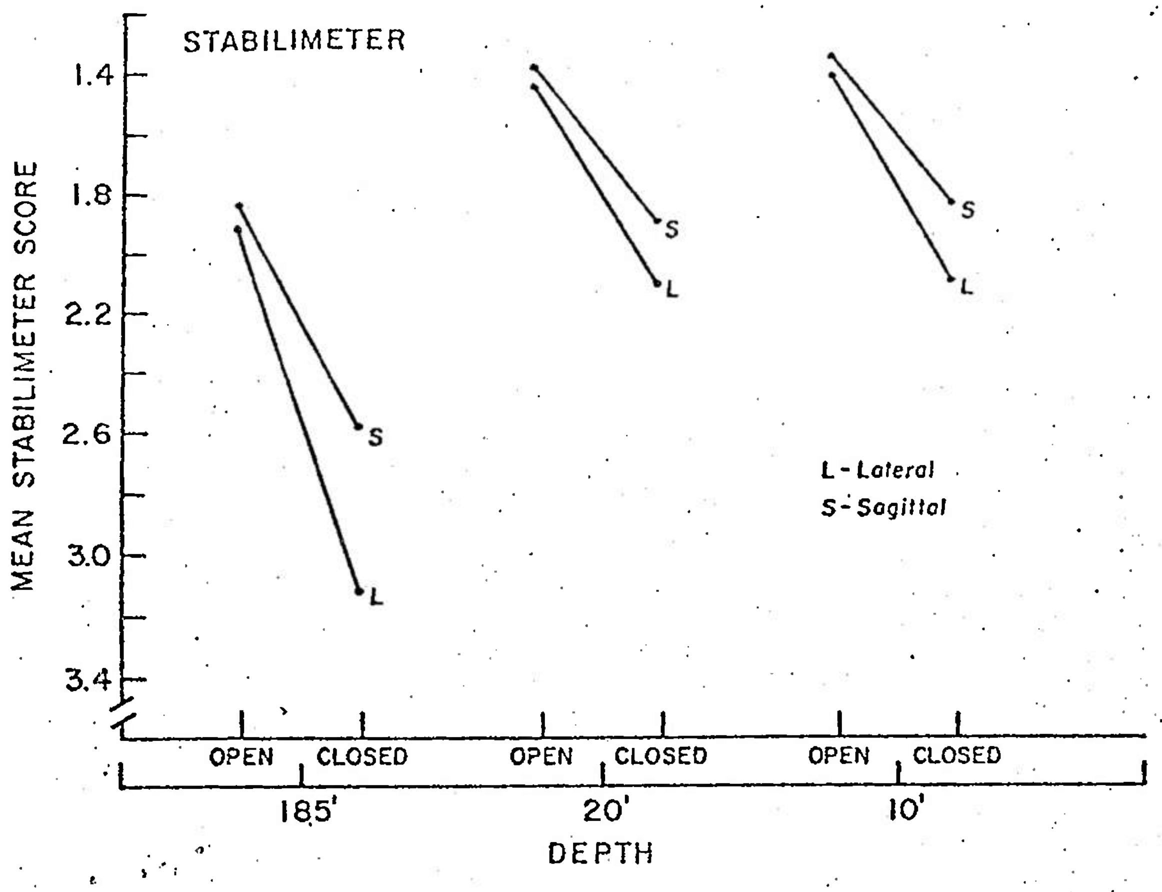
TRK
ADD
RT
MINN
ΔC
1.1
.9
.7
MEAN NUMBER CORRECT
22
18
14
MEAN NUMBER CORRECT
22
18
14
MEAN TIME, SECONDS
30
34
38
42
B 20 10 B 20 10 B 20 10 B 20 10 B 20 10
0 1 2 3 4
POST DIVE 1 ELAPSED TIME, DAYS
N=8 REPET II
* = LAST PRACTICE

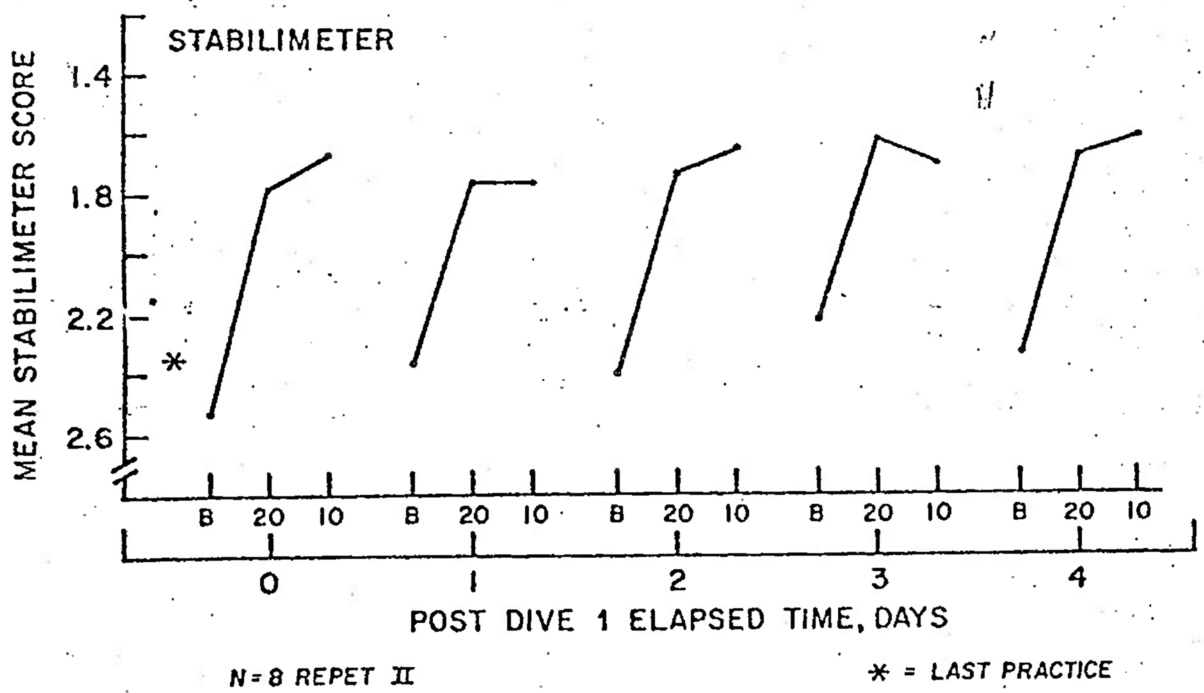


STABILIMETER
MEAN STABILIMETER SCORE
1.4
1.8
2.2
2.6
3.0
3.4
S
L
L - Lateral
S - Sagittal
OPEN
CLOSED
185'
20'
10'
DEPTH



STABILIMETER
MEAN STABILIMETER SCORE
1.4
1.8
2.2
2.6
*
B
20
10
0
1
2
3
4
POST DIVE 1 ELAPSED TIME, DAYS
N = 8 REPET II
* = LAST PRACTICE


STABILIMETER
MEAN STABILIMETER SCORE
1.4
1.8
2.2
2.6
3.0
3.4
L - Lateral
S - Sagittal
OPEN
CLOSED
185'
20'
10'
DEPTH


STABILIMETER
MEAN STABILIMETER SCORE
1.4
1.8
2.2
2.6
B
20
10
0
1
2
3
4
POST DIVE 1 ELAPSED TIME, DAYS
N=8 REPET II
* = LAST PRACTICE